WIRELESS LOCAL AREA NETWORK WITH
GEO-LOCATION CAPABILITY

Related Application

This application is based upon prior filed copending provisional application Serial No. 60/250,720 filed December 1, 2000, and prior filed copending provisional application Serial No. 60/257,014 filed December 20, 2000.

Field of the Invention

This invention relates to the field of wireless local area networks (WLAN), and more particularly, this invention relates to a wireless local area network that provides mobile device location.

Background of the Invention

Wireless local area networks are becoming more commonplace as the use of portable computers, such as "laptop," "notebook," and "pen" computers become increasingly common in office environments and other locations. In most conventional wireless local area networks, a number of access point base stations form a cellular network for communicating with wireless mobile stations or other mobile devices. Each access point base station is typically connected to a network server, such as part of an ethernet or other network infrastructure. Any messages transmitted as wireless communication signals are first transmitted to an access point base station instead of transmitted along

wireless stations. This type of centralized wireless communication using cells provides control over communications along existing wireless mobile devices. Typically, the wireless communication signals are a

5 spread spectrum communications signal, for example, a direct sequence spread spectrum signal, or a frequency hopping spread spectrum signal.

Although wireless local area networks are becoming more commonplace in offices and similar

10 environments, most wireless local area networks do not provide the capability of determining the location of a wireless mobile device operating in the wireless LAN environment. Although some wireless LAN systems provide for signal strength analysis of spread spectrum

15 signals to determine location, none of them provide an accurate means of determining the location of a mobile device operative within the wireless infrastructure defined by access point base stations.

20   **Summary of the Invention**

The present invention advantageously provides a system for locating a wireless station in communication with a wireless local area network. The system typically includes a network server, such as an

25 ethernet network server, that is operative with an ethernet local area network. A plurality of cells define a wireless local area network (WLAN), each having an access point base station and typically operatively connected to the server. Each access point

30 base station communicates with wireless mobile devices using wireless communication signals, such as spread spectrum communication signals. A processor is operatively connected to each of the access point base stations and operative to process communication signals

35 transmitted from a mobile device. The processor

determines which signals are first-to-arrive signals based on a common timing signal and conducts differentiation of the first-to-arrive signals to locate a mobile device.

5   In one aspect of the present invention, the common timing signal comprises a wireless timing signal broadcast to each of the access point base stations. This wireless timing signal could also be broadcast from a mobile device located at a known location or

10   from an access point base station. A common bus could be operatively connected to each of the access point base stations to which a common timing signal is provided. The common bus could be part of the LAN infrastructure connected to the network server, such as

15   an ethernet local area network.

          The wireless communication signal transmitted from the mobile devices could include a location pulse appended to the wireless communication signal. The location pulse could be appended to one of the rising

20   edge or falling edge of the wireless communication signal transmitted from a mobile device. This location pulse is typically a spread spectrum signal of short duration, i.e., a pulse.

          In yet another aspect of the present

25   invention, each base station could include edge detection circuitry for detecting the leading edge of a communication signal transmitted from a mobile device. This detected leading edge is processed and the first-to-arrive signals are determined based on a common

30   timing signal. A processor conducts differentiation of the first-to-arrive signals to locate the mobile device.

          In yet another aspect of the present invention, a correlator is time referenced with the

35   common timing signal and operative with each of the

access point base stations and receives a portion of a
wideband spread spectrum communication signal received
from a mobile device to determine first-to-arrive
signals and conduct differentiation of first-to-arrive
5   signals to locate the mobile device. This correlator
could include a spread spectrum matched filter and
associated processing circuitry.

Brief Description of the Drawings

10   Other objects, features and advantages of the
present invention will become apparent from the
detailed description of the invention which follows,
when considered in light of the accompanying drawings
in which:

15   FIG. 1 is an overall system diagram of the
location determination system of the present invention.
           FIG. 2 is a graph showing the appending of a
location pulse to a wireless communication signal.
           FIG. 3 is a block diagram showing an access
20   point base station having a wireless local area network
(WLAN) receiver that receives a wireless communications
signal and location receiver that receives a location
pulse.
           FIGS. 4A and 4B are block diagrams showing a
25   mobile device having a wireless local area network
(WLAN) transmitter for transmitting a wireless
communications signal and location transmitter that
transmits a location pulse that will be appended to the
wireless communications signal through a radio
30   frequency switch, and use of a signal detect circuit
(FIG. 4B).
           FIGS. 5A and 5B are block diagrams showing an
access point base station having an edge detector
circuit.

FIG. 6 illustrates another block diagram of an access point base station with an operatively connected correlator that could be a spread spectrum matched filter for wideband spread spectrum communications signals.

FIG. 7 is a high level block diagram of one example of the circuit architecture that can be used for a location receiver.

FIG. 8 is another high level block diagram of one example of the circuit architecture that can be used for a correlation-based, RF signal processor in accordance with the present invention.

Detailed Description of the Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

The present invention advantageously provides a system for locating a wireless mobile device, or mobile station (MS) as hereinafter referred, operating in communication with a wireless local area network (WLAN). Much of the technology and detection capability as associated with the system and method of the present invention can use the circuitry and algorithms described in commonly assigned U.S. Patent Nos. 5,920,287; 5,995,046; 6,121,926; and 6,127,976,

the disclosures which are hereby incorporated by reference in their entirety.

FIG. 1 illustrates a high level block diagram of the system **20** of the present invention and showing a
5 network server **22** that is part of an ethernet local area network **24**. A plurality of access point base stations **26** each define a cell (shown as **27a, 26b, 27c**) as part of a wireless local area network **30** that communicates with wireless mobile stations (MS) using
10 wireless communication signals that, in a preferred embodiment, are spread spectrum wireless communication signals. A processor **32** is operatively connected to each of the access point base stations and operative to process communication signals transmitted from a mobile
15 station and determine which signals are first-to-arrive signals based on a common timing signal. The processor conducts differentiation of the first-to-arrive signals to locate the mobile station. The processor function could also be incorporated with each access point base
20 station by incorporating a processor **32a** at each access point base station **26**. A common timing signal can be applied to each access point base station (and to processor **32** and **32a**) and could be provided by a wireless timing signal broadcast to each of the access
25 point base stations, such as by a mobile station (MS) located at a known location **34** or an access point base station that provides the common timing signal. In yet another aspect of the present invention, a common timing signal can be supplied through a common bus,
30 such as part of the ethernet structure.

FIG. 3 illustrates one type of access point base station **26** having a wireless local area network (WLAN) receiver **36** for receiving communications signals and a location receiver **38**, operatively connected to

the processor **32,32a** for determining which signals are first-to-arrive signals and conducting differentiation of the first-to-arrive signals to locate the mobile station. The receivers **36,38** can operate from the same

5   antenna **40**. As shown in FIG. 2, a wireless local area network communications signal **42** is transmitted from a mobile station (MS) and includes a spread spectrum location pulse **44** appended to the wireless communication signal. This location pulse **44** is a

10   short duration (typically less than one millisecond) spread spectrum transmission as a location pulse that is distinct and different from the wireless local area network communications signal. As shown in FIG. 2, the location pulse **44** can be appended to the falling edge

15   of the wireless communications signal or appended to the beginning or rising edge of the communications signal.

As shown in FIG. 4A, each mobile station (MS) preferably includes a wireless local area network

20   (WLAN) transmitter **46** for transmitting a communications signal, such as a spread spectrum communications signal, having appropriate data that is part of the mobile station transmission, including verification data and message data. A location transmitter **48** for

25   generating the location pulse **44** can be part of the mobile station (MS) and connect to a radio frequency (RF) switch **50** that forwards the communications signal **42** and pulse **44** to an antenna **52**. A controller **54** can be operatively connected to the wireless local area

30   network transmitter **46** and location transmitter **48** to operate the radio frequency switch **50** for determining proper transmission and appending of location pulse onto the communications signal, using synchronizing techniques known to those skilled in the art. It is

also possible that a signal detect circuit **56** (FIG. 4B) can be connected to the location transmitter **48** and wireless local area network transmitter **46** for detecting a transmission from the wireless local area

5   network transmitter and operatively signal the radio frequency switch **50** and location transmitter **48** for proper operation.   Various synchronizing concepts can be applied.

        The type of location pulse **44** that is

10 transmitted by the location transmitter **48** can vary, but typically comprises a direct sequence spread spectrum pulse, although a frequency hopping, chirp or other spread spectrum signal can also used.   The pulse is a short duration wideband spread spectrum pulse of

15 RF energy that can be about 100 millisecond duration. A repetition rate could vary with applications from tens of seconds to several hours, more or less as desired by those skilled in the art.   Further details of the type of pulse are set forth in the incorporated

20 by reference patents.

        For purposes of description, the type of location circuits, algorithm, and associated functions that can be used with the present invention, such as the processor functions and location receiver and

25 location transmitter, are set forth in the incorporated by reference patents.   For purposes of description, FIGS. 7 and 8 describe representative examples of circuit architectures that can be used for the location receiver and processor.

30   FIG. 7 diagrammatically illustrates one type of circuitry configuration of a respective location receiver (or "reader") architecture for "reading" location pulses or associated signals, "blink" as sometimes referred, such as emitted from a mobile

station. An antenna **210** senses appended transmission
bursts or other signals from a respective mobile
station. The antenna, which is preferably
omnidirectional and circularly polarized, is coupled to
5   a power amplifier **212**, whose output is filtered by a
bandpass filter **214**. Respective I and Q channels of
the bandpass filtered signal are processed in
associated circuits corresponding to that coupled
downstream of filter **214**. To simplify the drawing only
10 a single channel is shown.

A respective bandpass filtered I/Q channel is
applied to a first input **221** of a down-converting mixer
223. Mixer **223** has a second input **225** coupled to
receive the output of a phase-locked local IF
15 oscillator **227**. IF oscillator **227** is driven by a
highly stable reference frequency signal (e.g., 175
MHz) coupled over a (75 ohm) communication cable **231**
from a control processor. The reference frequency
applied to phase-locked oscillator **227** is coupled
20 through an LC filter **233** and limited via limiter **235**.

The IF output of mixer **223**, which may be on
the order of 70 MHz, is coupled to a controlled
equalizer **236**, the output of which is applied through a
controlled current amplifier **237** and applied to
25 communication cable **231** to a communication signal
processor, which could be associated processor **32,32a**.
The communication cable **231** also supplies DC power for
the various components of the location receiver by way
of an RF choke **241** to a voltage regulator **242**, which
30 supplies the requisite DC voltage for powering an
oscillator, power amplifier and analog-to-digital units
of the receiver.

The amplitude of the (175 MHZ) reference
frequency supplied by the communications control

processor to the phase locked local oscillator **227**
implies the length of any communication cable **231**
between the processor and the receiver. This magnitude
information can be used as control inputs to equalizer

5   **236** and current amplifier **237**, so as to set gain and/or
a desired value of equalization, that may be required
to accommodate any length of a communication cable.
For this purpose, the magnitude of the reference
frequency may be detected by a simple diode detector

10 **245** and applied to respective inputs of a set of gain
and equalization comparators shown at **247**. The outputs
of comparators are quantized to set the gain and/or
equalization parameters.

FIG. 8 diagrammatically illustrates the

15 architecture of a correlation-based, RF signal
processor as part of processor **32** and/or **32a** to which
the output of a respective RF/IF conversion circuit of
FIG. 7 can be coupled for processing the output and
determining location. The correlation-based RF signal

20 processor correlates spread spectrum signals detected
by its associated receiver with successively delayed or
offset in time (by a fraction of a chip) spread
spectrum reference signal patterns, and determines
which spread spectrum signal received by the receiver

25 is the first-to-arrive corresponding to a "blink" or
location pulse from the location transmitter as part of
the communications signal that has traveled over the
closest observable path between the mobile station and
the location receiver.

30 Because each receiver can be expected to
receive multiple signals from the mobile station, due
to multipath effects caused by the signal transmitted
by the mobile station being reflected off various
objects/surfaces between the mobile station and the

receiver, the correlation scheme ensures identification
of the first observable transmission, which is the only
signal containing valid timing information from which a
true determination can be made of the distance from the
5 tag to the receiver.

For this purpose, as shown in FIG. 8, the RF
processor employs a front end, multi-channel digitizer
300, such as a quadrature IF-baseband down-converter
for each of an N number of receivers. The quadrature
10 baseband signals are digitized by associated analog-to-
digital converters (ADCs) **272I** and **272Q**. Digitizing
(sampling) the outputs at baseband serves to minimize
the sampling rate required for an individual channel,
while also allowing a matched filter section **305**, to
15 which the respective channels (reader outputs) of the
digitizer **300** are coupled to be implemented as a
single, dedicated functionality ASIC, that is readily
cascadable with other identical components to maximize
performance and minimize cost.

20 This provides an advantage over bandpass
filtering schemes, which require either higher sampling
rates or more expensive ADCs that are capable of
directly sampling very high IF frequencies and large
bandwidths. Implementing a bandpass filtering approach
25 typically requires a second ASIC to provide an
interface between the ADCs and the correlators. In
addition, baseband sampling requires only half the
sampling rate per channel of bandpass filtering
schemes.

30 The matched filter section **305** may contain a
plurality of matched filter banks **307**, each of which is
comprised of a set of parallel correlators, such as
described in the above identified, incorporated by
reference '926 patent. A PN spreading code generator

could produce a PN spreading code (identical to that produced by the PN spreading sequence generator of the location transmitter). The PN spreading code produced by PN code generator is supplied to a first correlator

5   unit and a series of delay units, outputs of which are coupled to respective ones of the remaining correlators. Each delay unit provides a delay equivalent to one-half a chip. Further details of the parallel correlation are found in the incorporated by

10   reference '926 patent.

As a non-limiting example, the matched filter correlators may be sized and clocked to provide on the order of 4×10^6 correlations per epoch. By continuously correlating all possible phases of the PN spreading

15   code with an incoming signal, the correlation processing architecture effectively functions as a matched filter, continuously looking for a match between the reference spreading code sequence and the contents of the incoming signal. Each correlation

20   output port **328** is compared with a prescribed threshold that is adaptively established by a set of 'on-demand' or 'as needed' digital processing units 340-1, 340-2, ..., 340-K. One of the correlator outputs **328** has a summation value exceeding the threshold, which delayed

25   version of the PN spreading sequence is effectively aligned (to within half a chip time) with the incoming signal.

This signal is applied to a switching matrix **330**, which is operative to couple a 'snapshot' of the

30   data on the selected channel to a selected digital signal processing unit **340-i** of the set of digital signal processing units **340**. The mobile station can 'blink' or transmit location pulses randomly, and can be statistically quantified, and thus, the number of

35   potential simultaneous signals over a processor revisit

time could determine the number of such 'on-demand'
digital signal processors required. A processor would
scan the raw data supplied to the matched filter and
the initial time tag. The raw data is scanned at
5   fractions of a chip rate using a separate matched
filter as a co-processor to produce an auto-correlation
in both the forward (in time) and backwards (in time)
directions around the initial detection output for both
the earliest (first observable path) detection and
10   other buried signals. The output of the digital
processor is the first path detection time, threshold
information, and the amount of energy in the signal
produced at each receiver's input, which is supplied to
and processed by the time-of-arrival-based multi-
15   lateration processor section **400**.

        Processor section **400** uses a standard multi-
lateration algorithm that relies upon time-of-arrival
inputs from at least three detectors to compute the
location of the object. The algorithm may be one which
20   uses a weighted average of the received signals. In
addition to using the first observable signals to
determine object location, the processor also can read
any data read out of a mobile station's memory and
superimposed on the transmission. Object position and
25   parameter data can be downloaded to a data base where
object information is maintained. Any data stored in a
mobile station memory may be augmented by altimetry
data supplied from a relatively inexpensive,
commercially available altimeter circuit. Further
30   details of such circuit are found in the incorporated
by reference '926 patent.

        It is also possible to use an enhanced
circuit as shown in the incorporated by reference '926
patent to reduce multipath effects, by using dual
35   antenna and providing spatial diversity-based

mitigation of multipath signals. In such systems, the antennas of each location receiver at a base station are spaced apart from one another by a distance that is sufficient to minimize destructive multipath

5 interference at both antennas simultaneously, and also ensure that the antennas are close enough to one another so as to not significantly affect the calculation of the location of the object by the downstream multi-lateration processor.

10 The multi-lateration algorithm executed by the processor is modified to include a front end subroutine that selects the earlier-to-arrive outputs of each of the detector pairs as the value to be employed in the multi-lateration algorithm. A

15 plurality of auxiliary 'phased array' signal processing paths can be coupled to the antenna set (e.g., pair), in addition to the paths containing the directly connected receivers and their associated first arrival detector units that feed the triangulation processor.

20 Each respective auxiliary phased array path is configured to sum the energy received from the two antennas in a prescribed phase relationship, with the energy sum being coupled to associated units that feed a processor as a triangulation processor.

25 The purpose of a phased array modification is to address the situation in a multipath environment where a relatively 'early' signal may be canceled by an equal and opposite signal arriving from a different direction. It is also possible to take advantage of an

30 array factor of a plurality of antennas to provide a reasonable probability of effectively ignoring the destructively interfering energy. A phased array provides each site with the ability to differentiate between received signals, by using the 'pattern' or

spatial distribution of gain to receive one incoming
signal and ignore the other.

5   The multi-lateration algorithm executed by
the processor could include a front end subroutine that
selects the earliest-to-arrive output of its input
signal processing paths and those from each of the
signal processing paths as the value to be employed in
the multi-lateration algorithm (for that receiver
site). The number of elements and paths, and the gain
10   and the phase shift values (weighting coefficients) may
vary depending upon the application.

It is also possible to partition and
distribute the processing load by using a distributed
data processing architecture as described in the
15   incorporated by reference 6,127,976 patent. This
architecture can be configured to distribute the
workload over a plurality of interconnected information
handling and processing subsystems. Distributing the
processing load enables fault tolerance through dynamic
20   reallocation.

The front end processing subsystem can be
partitioned into a plurality of detection processors,
so that data processing operations are distributed
among sets of detection processors. The partitioned
25   detection processors are coupled in turn through
distributed association processors to multiple location
processors. For maximum mobile station detection
capability, each receiver is preferably equipped with a
low cost omnidirectional antenna, that provides
30   hemispherical coverage within the monitored
environment.

A detection processor filters received energy
to determine the earliest time-of-arrival energy
received for a transmission, and thereby minimize
35   multi-path effects on the eventually determined

location of a mobile device. The detection processor
demodulates and time stamps all received energy that is
correlated to known spreading codes of the
transmission, so as to associate a received locatoin

5 pulse with only one mobile station. It then assembles
this information into a message packet and transmits
the packet as a detection report over a communication
framework to one of the partitioned set of association
processors, and then de-allocates the detection report.

10   A detection processor to association control
processor flow control mechanism equitably distributes
the computational load among the available association
processors, while assuring that all receptions of a
single location pulse transmission, whether they come

15 from one or multiple detection processors, are directed
to the same association processor.

            The flow control mechanism uses an
information and processing load distribution algorithm,
to determine which of the association processors is to

20 receive the message, and queues the message on a
prescribed protocol coupling socket connecting the
detection processor to the destination association
processor. To select a destination association
processor, the information and processing load

25 distribution algorithm may include a prime number-based
hashing operation to ensure a very uniform distribution
of packets among association processors. In addition,
to provide relatively even partitioning in the case of
widely varying transmission rates, the hashing

30 algorithm may use a sequence number contained in each
transmission.

            Each association processor can organize its
received message packets by identification (ID) and
time-of-arrival (TOA), and stores them as association

35 reports. The association processor compresses the data

within the association report, transmits that
information over an association communication process
of the communication framework to one of a plurality of
distributed location processors, and then de-allocates
5   the association report.

In order to deliver all association reports
that have been generated for an individual mobile
station (or device) to a single destination location
processor, the association communication process of the
10 communication framework may employ the same information
and processing load distribution algorithm executed by
the detection communication process of the
communication framework. Each location processor
determines the geographical location of a mobile
15 station using the time-of-arrival measurement
information originally sourced from the detection
processors. The specific algorithm employed for
location determination matches the number of arrival
time measurements with whatever a priori information is
20 available.

To locate a mobile station, a location
processor may employ all available diversity
information associated with the mobile station of
interest, including, but not limited to the mobile
25 station ID, any data contained in the transmission and
metrics indicating confidence it these values. It then
forwards a location report containing this information
over a location communication process to an asset
management data base. A location estimate may be
30 derived from the measured time-of-arrival information
in a received association report packet, using a
differential time-of-arrival algorithm, such as a
hyperbolic geometry-based function.

It is also possible to use a wireless local
35 area network (WLAN) spread spectrum waveform to perform

the geo-location function of the present invention. The assumption is that the wireless communication signal, as a spread spectrum signal, has a high signal-to-noise ratio with reasonable power levels. The

5 leading edge of this communication signal can be detected to a high accuracy and this information used with the algorithms as described before to provide relative time of arrival information for subsequent processing. FIG. 5A shows edge detector circuitry **60**

10 as part of an access point base station **26** having the wireless local area network (WLAN) receiver **36**. It is also possible to have a timing signal from a known location or unknown location as shown in FIG. 5B. Other component locations would have to be known, of

15 course. For example, some wireless local area network (WLAN) transmitters have known locations to enable the use of the algorithm when an access point base station or mobile station location is known.

It is also known that the communications

20 signal as a spread spectrum communications signal can have sufficient bandwidth to provide useful time accuracy. For example, a 50 MHz bandwidth could provide approximately 5 nanoseconds of timing accuracy that is about 5 feet of accuracy using much of the

25 technology and teachings described before. It is possible to use a correlator **62** operative as a functional spread spectrum matched filter to enable a higher quality estimate with integration over many chips of the spread spectrum transmission (FIG. 6). It

30 is possible to use a matched filter that spans multiple symbols and improve accuracy by collecting more energy in the filter prior to leading edge detection.

Many modifications and other embodiments of the invention will come to the mind of one skilled in

35 the art having the benefit of the teachings presented

in the foregoing descriptions and the associated
drawings. Therefore, it is to be understood that the
invention is not to be limited to the specific
embodiments disclosed, and that the modifications and
5   embodiments are intended to be included within the
scope of the dependent claims.